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Research Article

Comparative study of drip irrigation effects on tomato (*Solanum lycopersicum* L.) production under greenhouse and open field on ferralitic soil in Southern Benin

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Tomato, drip irrigation, soilless culture, greenhouse, open field, profitability.

Abstract

Drip irrigation is a key technology for efficient water management in vegetable production in Benin, particularly in the face of climate change. This study, conducted at the experimental station of Agonkanmey of the National Institute of Agricultural Research of Benin (INRAB), aimed to improve tomato production under greenhouse conditions in southern Benin by comparing two cropping systems which are soil-based and soilless. The assessment focused on the hydraulic performance of the drip irrigation system, plant growth and yield, as well as the financial profitability of greenhouse and open-field production systems. The results showed moderate uniformity of water distribution (70 to 90%, according to CEMAGREF standards). The soilless system produced the most vigorous plants, with the highest yields in the open field (26.42 t/ha), and greenhouse (23.16 t/ha) and the best water-use efficiency (27.07 kg/m^3 in open field and 8.33 kg/m^3 in greenhouse). Economically, the highest gross margin was obtained from soilless culture under greenhouse (26,046 FCFA) conditions, whereas a loss was recorded with soil-based cultivation in open fields. In conclusion, soilless greenhouse production proved to be the most profitable option, highlighting its potential as a sustainable and economically viable strategy for intensifying tomato production in Southern Benin. Scaling it up would ensure the continuous availability of tomatoes.

1. Introduction

Agriculture is the largest consumer of water worldwide, accounting for approximately 70% of the total withdrawals from rivers, lakes, and aquifers [1]. However, a significant portion of this water is lost due to evapotranspiration, inefficient water transport, and weed growth. The availability of water, an essential economic and social resource, is increasingly constrained by climate change, declining water quality, rising demand, and growing conflicts over its use. This situation is particularly critical in Sub-Saharan Africa, a region heavily dependent on agriculture and highly vulnerable to climate-related risks [2]. Many countries have invested in improved water management technologies to support more resilient agricultural systems to address these challenges [3]. The development of land management models and water control practices adapted to specific crops has helped reduce the risks associated with drought or flooding, while extending the length of growing seasons [4]. Previous efforts to address the efficient use of water in the agriculture sector have focused on water productivity, measured as the quantity of crop (yield) or economic value per unit of water used (crop per drop), suggested by [5]. In Benin, agriculture remains largely rain-fed, with average annual rainfall ranging from 750 to 1,400 mm. However, the spatial and temporal distributions of rainfall do not always align with crop water requirements [6]. To address this limitation, various production strategies have been introduced, including lowland cropping, flood-recession farming, and irrigated agriculture. In this context, tomato cultivation has gained renewed interest through the adoption of systems that integrate irrigation with modern techniques, such as greenhouse farming. Although, protected cultivation systems are still underdeveloped in Africa (2.5% of horticultural areas) according to Langlais et al. [7], they are widely used in other climatic regions, including the Mediterranean (28%), temperate (60%), and tropical/subtropical (12%) regions. These systems not only improve yields but also allow off-season production and the cultivation of crops outside their ecological zones of origin [8-9]. Depending on their level of sophistication, protected systems range from simple plastic tunnels to complex glass-greenhouses. However, few studies have conducted a comparative analysis of the combined effects of drip irrigation and cultivation methods (soil against soilless) on tomato production, particularly under ferralitic soil conditions in southern Benin. For instance, [10] compared water-use efficiency, yield, and economic viability of greenhouse-grown tomatoes under soilless (using substrate + gravel) versus soil-based cultivation, both under drip irrigation. The authors found that the soilless method almost doubled water productivity compared with soil-based cultivation, while saving 50% of irrigation water. Additionnaly, Mensah et al. [11] compared tomatoes grown in soil with two hydroponic systems (including one drip- or substrate-based hydroponic system) under controlled environments (glasshouse or polytunnel). They showed that hydroponically grown plants used less water, had higher water-use efficiency, and in some cases, produced fruits with equal or improved nutritional quality compared to soil-grown tomatoes. Therefore, this study was initiated to address this knowledge gap.

2. Materials and methods

2.1. Materials

2.1.1. Study area

This study was carried out over two cycles of on-station examination at the vegetable program of the National Research Agricultural Institute of Benin (INRAB) based at Agonkanmey (6°24′35′′ North and 2°19′55′′ East) [12].

2.1.2. Greenhouse description

The 300 m² greenhouse was a closed structure made of plastic film and insect-proof netting, supported by a metal frame. It is equipped with a drip irrigation system for both soilless and in-ground cultivation, consisting of a main supply line, head unit, manifold lines, and emitters spaced 30 cm apart. Two climate control devices installed on the ceiling fans and misting systems ensured air circulation, heat control, and temperature regulation to maintain an optimal environment for the plants, as shown in Fig. 1.

2.2. Methods

2.2.1. Experimental design

The experimental design used over the two cycles was a non-replicated split-plot with two factors. The main factor was the growing environment, with two levels: greenhouse and open-field. The secondary factor was the cultivation method, which also had two levels: in-ground and soilless cultivation (Table 1).

2.3. Data collection

2.3.1. Data on the hydraulic performance of the drip irrigation system

For the two experimentation cycles, the uniformity coefficient (Cu) was determined using the method by measuring the water volume from 16 emitters per treatment, and distributed along each irrigation line [13]. The volumes were collected in containers or buckets and measured using graduated cylinders. The Cu was calculated and compared with the standards [13].

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Figure 1. Greenhouse exterior view: A: front view showing the entrance airlock, B: side view showing the netting that forms the roof of the greenhouse.

Table 1. Summary of the different treatments.

Cultivation method	Cultivation Environment	
	Greenhouse	Open field
In-ground (soil)	T1: In-ground treatment	T3: In-ground treatment
Soilless	T2: Soilless treatment	T4: Soilless treatment

Uniformity Coefficient (CU) =

$$100\times\left(1-\frac{1.27^{*}Cv}{\sqrt{n}}\right)\times\frac{\text{qmin}}{\text{qaveg}}$$

Where:

-Cv: Coefficient of variation;

-n: Number of emitters per plot;

-qmin: Minimum discharge (L/h);

- qaveg: Average discharge of all emitters in the plot (L/h);
- Cu > 90%: good uniformity;
- 70% < Cu < 90%: average uniformity;
- Cu < 70%: poor uniformity.

2.3.2. Agro-morphological and yield parameters of tomato

The agro-morphological parameters of tomato included growth measurements (height and collar diameter measured weekly) and phenological development (number of flowers and fruits per cluster, dates of 50% flowering and fruiting) were taken over the two cycles. Yield was evaluated based on the weight of healthy, necrotic, rotten and damaged fruits, with the potential yield calculated in tons per hectare (t/ha).

The potential yield (T/ha) was calculated as follows:

Potential yield (t/ha)=

$$\frac{\text{Total weight of harvested fruits (kg)}\times 10{,}000\ (\mathrm{m}^2)}{\text{Treatment area }(\mathrm{m}^2)\times 1000\text{ (kg)}}$$

Fruit sizing was performed on 30 fruits per treatment according to size intervals (30–35, 35–40, 40–47, 47–57, 57–67, 67–82 and 82–102 mm).

Marginal financial profitability takes into account variable costs related to inputs and labor, whereas revenue was calculated from the quantity harvested, multiplied by the unit price. The gross margin corresponds to the difference between revenue and total variable costs.

2.4. Statistical data analysis

Plant height and collar diameter, which are continuous quantitative data measured over time, were analyzed using a linear mixed-effects longitudinal model to test the effects of the environment and cultivation method on their variations. Yield data were analyzed using a linear model, followed by analysis of variance (ANOVA). Fruits were also sized, and the mean number of fruits per size class was calculated for each production system and cultivation method. The environment and cultivation methods were considered fixed factors, while time (number of days after transplanting) was treated as a random factor. This analysis was performed using the "nlme" package [14]. Marginal and conditional R^2 values for the linear mixed-effects longitudinal model were calculated using the

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r.squaredGLMM() function from the MuMIn package [15], which implements the method developed by Wickham [16]. The marginal R^2 represents the variance explained by the fixed effects, whereas the conditional R^2 represents the variance explained by the entire model, including both fixed and random effects. Growth curves of the various parameters over time were generated using the “ggplot2” package [17]. All analyses and visualizations were performed using R software (version 4.3.0) [18].

3. Results and discussion

3.1. Uniformity coefficient

Over the two cycles, the irrigation uniformity coefficients (Cu), measured in the open field (79.18% and 86.1%) and greenhouse (78.75% and 82.56%) were below the [13] standards, indicating moderate uniformity in water distribution. Overall, the Cu values ranged between 70% and 90%, corresponding to moderately uniform irrigation (Fig. 2).

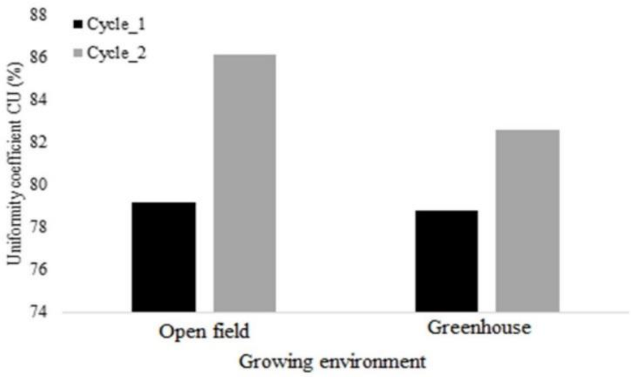

Figure 2. Variation in the uniformity coefficient according to the growing environment.

The results obtained in this study reveal several contrasts compared to the literature references, but also convergences that enrich the understanding of the local tomato production conditions. The irrigation uniformity coefficients were lower than those reported by several authors [19], highlighting the need for better network management to ensure a homogeneous water distribution. The study of [20] measured uniformity (Coefficient of Uniformity, Distribution Uniformity, etc.) under surface drip irrigation and found high CU (≈ 95.6-97%) when systems were maintained, leveled and well managed. [21] analyzed how different levels of uniformity influence yield and dry matter content. This study emphasized that water distribution uniformity has concrete effects on both the quantity and quality of tomato production.

3.2. Agronomic parameters

3.2.1. Plant height and collar diameter

The growing environment, cultivation method, and their interaction ($p < 2.2e-16$) significantly influenced tomato plant height and collar diameter at the 5% level, with diameter also depending on the crop cycle. Greenhouse cultivation promoted vertical growth (154.65 cm, cycle 2), whereas open-field cultivation, particularly in soilless conditions produced the largest collar diameters (13.23 mm, cycle 1). Moreover, the greenhouse provided stability in the collar diameter (10 mm) (Fig. 3).

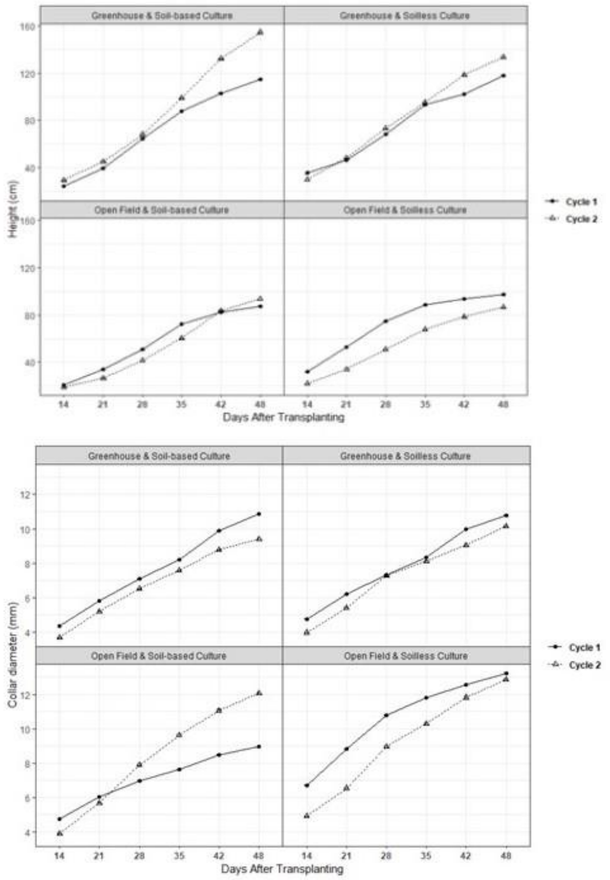

Figure 3. Evolution of plant height and collar diameter according to the environment, cultivation method, and crop cycle.

Thus, greenhouse conditions, favor plant height and uniformity, whereas soilless open-field cultivation enhances plant sturdiness. Vegetatively, average heights and stem diameters in the open field are generally below the literature references [22],

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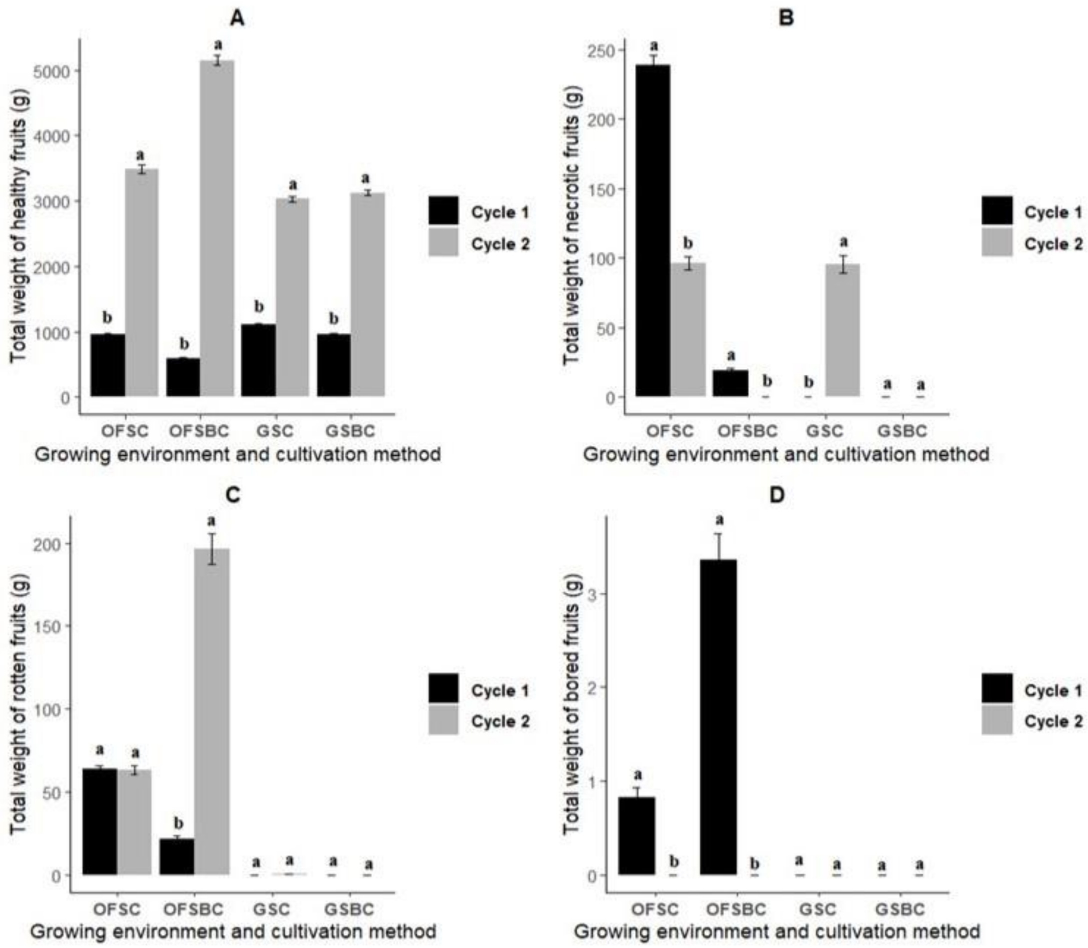

Figure 4. Variation in the total weight of healthy fruits (A), necrotic fruits (B), rotten fruits (C), and bored fruits (D) according to the growing environment, cultivation method and crop cycle. OFSC = Open Field & Soilless Culture, OFSBC = Open Field & Soil-based Culture, GSC = Greenhouse & Soilless Culture, GSBC = Greenhouse & Soil-based Culture.

although the soilless system promoted better growth than the open field. The study of [23] on the comparative performance of tomato cultivars in soilless production systems found that plants grown in soilless systems had faster development and higher yield than in-soil cultivation.

3.2.2. Yield

The cultivation method, growing environment, and their interaction significantly influenced the total weight of healthy fruits ($p = 5.03e-08$), necrotic fruits ($p = 3.66e-13$), rotten fruits ($p = 5.42e-10$), marketable fruits ($p = 1.51e-11$), and potential yield ($p = 4.64e-11$) across crop cycles at 5% level. In the first cycle, the greenhouse (soilless: 1,108.11 g; in-ground: 960.36 g) produced higher average weights of healthy fruits compared to the open field (Fig. 4). However, in the second cycle, the highest values were recorded in the open field (soilless = 3,493.13 g; in-ground = 5,149.12 g). The greenhouse, in addition to providing a controlled environment, helped reduce blossom-end rot and stabilized production, even though the open field showed better performance in the second cycle.

Overall, yields were higher in the second cycle, with a maximum recorded in the open-field in-ground treatment (111.37 t/ha) and soilless (76.09 t/ha), compared to lower yields in the open-field in-ground treatment during the first cycle (13.46 t/ha). A consistent yield of 65 t/ha was recorded in the greenhouse, regardless of the treatment (Fig. 5). Thus, in-ground open-field cultivation shows strong potential under favorable conditions, but soilless cultivation remains the most reliable option for continuous and secure production.

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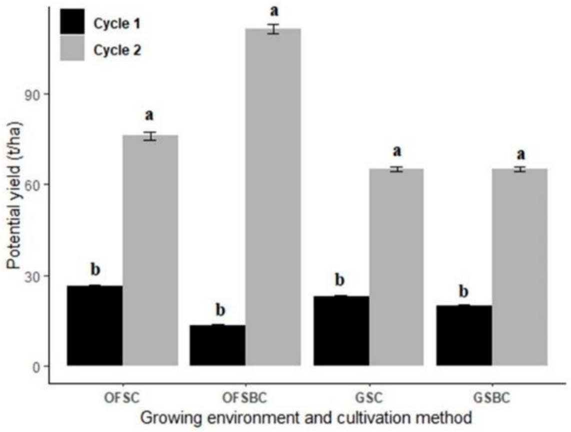

Figure 5. Variation in potential tomato yield according to the growing environment, cultivation method, and crop cycle. OFSC = Open Field & Soilless Culture, OFSBC = Open Field & Soil-based Culture, GSC = Greenhouse & Soilless Culture, GSBC = Greenhouse & Soil-based Culture.

3.2.3. Fruit sizing

The distribution of fruits by size, which is crucial for commercial value, was strongly influenced by the interaction of factors ($p = 0.0059$). Fruits grown in the greenhouse were generally smaller, mostly ranging between 35–57 mm during the first cycle and 47–67 mm in the second cycle. In the open field, fruits were larger, predominantly within the 47–67 mm range, with some larger sizes (67–102 mm). The in-ground treatment in the open field produced 58 fruits sized 47–57 mm and 5 fruits sized 82–102 mm, while the soilless treatment yielded 59 fruits sized 57–67 mm and 6 fruits sized 67–82 mm (Fig. 6).

The findings of [24] compared several soilless substrates (peat, vermiculite, and perlite combinations) and soil cultivation. They found that for some substrates, soilless cultivation performed similarly or even better but, soil sometimes had better growth of yield depending on the substrate and climate. These differences are mainly explained by seasonality and microclimatic conditions of the region. The study of [25] found that soil nutrient applications of Ca, B, and Zn reduce BER and other physiological disorders, and improve yield. That study corroborated this research and observed that specific applications can correct disorders. [26] found that evapotranspiration, and phenology (crop coefficients) differ under different systems and microclimatic conditions. Their work showed how growth in soilless/open systems responds to the radiation climate.

Finally, yields are at an intermediate level: higher than national production according to statistics [27] and Arouna et al. [28] in Togo. These performances reflect the importance of water availability in the root zone as well as the influence of high temperatures on fruit quality [29]. Overall, the study confirmed that irrigation management, microclimate control, and choice of cultivation system are essential levers to improve tomato productivity and quality in the local context.

3.3. Marginal financial profitability of tomato production

Cost analysis shows that producing PADMA tomatoes is more expensive in the greenhouse (44,873–45,833 FCFA) than in the open field (41,183–41,473 FCFA), mainly due to the increased use of twine for staking and specific maintenance operations, such as tying (Table 2).

Although the gross revenue and variable costs are higher in the greenhouse than in the open field, the gross margin remains higher under greenhouse conditions, especially for soilless treatments. In the second production cycle, greenhouse margins were considerably higher at 216,751 FCFA in the soilless system and 207,821 FCFA in the soil-based system compared with 135,082 and 194,661 FCFA, respectively, in open-field cultivation. This profitability differential is largely attributable to the higher selling prices obtained in greenhouse conditions, where tomatoes exhibited better visual quality and uniformity (800 and 600 FCFA/kg), whereas fruits from the open field were sold for only 600 and 300 FCFA/kg. A loss of 10,000 FCFA was recorded in the first cycle for soil-based open-field production. These trends are consistent with the findings that greenhouse environments enhance fruit quality, reduce pest and disease pressure, and increase market value relative to open-field systems [30-31]. Likewise, soilless cultivation systems have been widely reported to improve yield uniformity, nutrient use efficiency, and economic returns [32-33]. Overall, while soilless greenhouse production emerges as the most profitable option, a full economic assessment, including net margin analysis, is required to accurately determine long-term financial viability.

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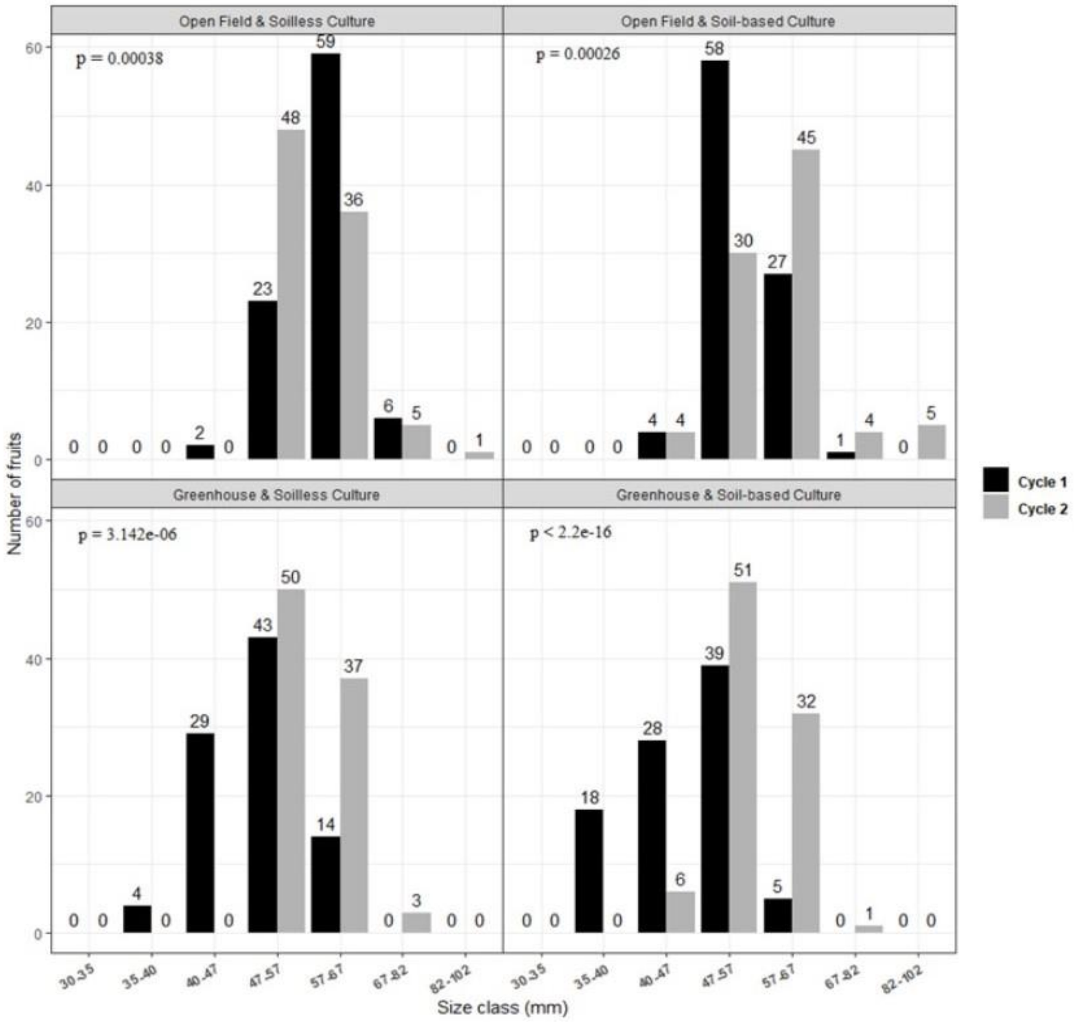

Figure 6. Number of fruits by size class according to the growing environment, cultivation method, and tomato production season.

Table 2. Gross product and Gross margin.

Rubric	**Greenhouse**				**Open field**			
Mode	**Cycle 1**		**Cycle 2**		**Cycle 1**		**Cycle 2**	
	Soilless	**Soil**	**Soilless**	**Soil**	**Soilless**	**Soil**	**Soilless**	**Soil**
A. Total Production (Kg)	88.65	76.83	523.25	507.31	101.75	51.96	588.52	786.15
B. Unit selling price (Fcfa/kg)	800	800	500	500	600	600	300	300
C. Gross product (Fcfa) (C=AXB)	70,920	61,464	261,625	253,655	61,050	31,176	176,556	235,845
D. Variable charges	44,873.37	45,833.37	44,873.37	45,833.37	41,473.37	41,183.37	41,473.37	41,183.37
E. Gross margin (Fcfa) (C-D)	26,046.63	15,630.63	216,751.63	207,821.63	19,576.63	-10,007.3	135,082.63	194,661.63

4. Conclusions

This study demonstrated that integrating drip irrigation with soilless cultivation significantly enhances tomato growth, yield, and water-use efficiency compared with soil-based systems in both greenhouse and open-field environments. The hydraulic performance of the drip system was within acceptable standards, supporting its suitability for vegetable production under the climatic conditions of southern Benin. Overall, soilless greenhouse production proved to be the most profitable option, highlighting its potential as a sustainable and economically viable strategy for intensifying tomato production in the region. Scaling it up would ensure the continuous availability of tomatoes.

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Disclaimer (artificial intelligence)

Author(s) hereby state that no generative AI tools such as Large Language Models (ChatGPT, Copilot, etc.) and text-to-image generators were utilized in the preparation or editing of this manuscript.

Authors' contributions

Conceptualization; project administration; resources; methodology; data preservation; formal analysis; supervision; software; validation; visualization; writing—original version; writing—revision and editing, M.A.C.G.; conceptualization, investigation, methodology, software, formal analysis, validation, writing, K.W.T.; methodology, data collection, formal analysis, writing-original version, A.D.A.J.; methodology, data collection, writing-original version, A.F.K.; methodology, software, formal analysis, validation, writing, Y.F.; supervision, writing - original version, B.A.

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Availability of data and materials

All data will be made available on request according to the journal policy.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Silva, D.J. World importance, marketing and trading of vegetables. Acta Horticulture. 2011, 921, 153-169. https://doi.org/10.17660/ActaHortic.2011.921.18
2. Malézieux, E.; Crozat, Y.; Dupraz, C.; Laurans, M.; Makowski, D.; Ozier Lafontaine, H.; Rapidel, B.; De Tourdonnet, S.; Valantin-Morison, M. Mixing plant species in cropping systems: concepts, tools and models. A review. Agr. Sust. Dev. 2009, 29 (1), 43-62. https://doi.org/10.1051/agro:2007057
3. Van Heurn, E.; Van der Post, K. Agrodok 23, Agriculture sous abri : Structure, conditions requises et usage des serres sous différents climats, 1ère édition Digigrafi, Wageningen, Pays-Bas. 2004. ISBN: 90-77073-37-X, NUGI:835. https://hdl.handle.net/10568/73069
4. Renault, D.; Wallender, W.W. Nutritional water productivity and diets: From "Crop per Drop" towards: "Nutrition per Drop". Agric. Water Manage. 2000, 45, 275-296. http://dx.doi.org/10.1016/S0378-3774(99)00107-9
5. Van Halsema, G.E.; Vincent, L. Efficiency and productivity terms for water management: a matter of contextual relativism versus general absolutism. Agric. Water Manag. 2012, 108, 9-15. https://doi.org/10.1016/j.agwat.2011.05.016
6. Letard, M. Maîtrise de l'irrigation tomate sous serre et abris en sol. Paris, France, CTIFL. 2000. 220 p. ISBN: 2-87911-068-8. ⟨hal-02852839⟩. https://hal.inrae.fr/hal-02852839
7. Langlais, C.; Ryckewaert, P. Guide de la culture sous abri en zone tropicale humide. Edition Chantal Loison, Service des publications, CIRAD – FLHOR. p.91, 2000.
8. Mensah, A.C.G.; Koura, T.W.; Yarou, B.B.; Assogba, C.M.A.; Taboe, H.B.; Assogba Komlan, F.; Amadji, G.L. Tomato production in off-season: Assessment of the influence of transplanting dates on virus incidence and yield in Benin. Agrosyst. Geosci. Environ. 2025, 8, e70068. https://doi.org/10.1002/agg2.70068
9. Al-Khateeb, S.A.; Zeineldin, F.I.; Elmulthu, N.A.; Al-Barrak, K.M.; Sattar, M.N.; Mohammad T.A.; Mohmand A.S. Assessment of water productivity and economic viability of greenhouse-grown tomatoes under soilless and soil-based cultivations. Water. 2024, 16(7), 987. https://doi.org/10.3390/w16070987
10. Verdoliva, S.; Jones, D.; Detheridge, A.; Robson, P. Controlled comparisons between soil and hydroponic systems reveal increased water use efficiency and higher lycopene and β-carotene contents in hydroponically grown tomatoes. Sci. Hort. 2021, 279, 109896. https://doi.org/10.1016/j.scienta.2021.109896
11. Mensah, A.C.G.; Azagba, J.A.D.; Koura, T.W.; Anato, F.M.; Bokonon-Ganta, A.H. Efficacité de la diatomite et du kaolin en formulation aqueuse pour le contrôle de *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), de *Hellula undalis* (F.) (Lepidoptera: Pyralidae) et de *Lipaphis erysimi* (Kalt.) (Hemiptera: Aphididae) sur le chou au Sud Bénin. Bulletin de la Recherche Agronomique du Bénin (BRAB), 2025, 35(4). https://doi.org/10.62344/hj189r26
12. CEMAGREF. Irrigation - Guide pratique. Editions du CEMAGREF, France, 342p.

13. Pinheiro, J.; Bates, D.; R Core Team. 2023. _nlme: Linear and Nonlinear Mixed Effects Models_. R package version 3.1-162, <https://CRAN.R-project.org/package=nlme>.
14. Barton, K. MuMIn: Multi-Model Inference. 2016. Available from: https://cran.rproject.org/web/packages /MuMIn/index.html.
15. Nakagawa, S.; Schielzeth, H.A. General and simple method for obtaining R-squared from generalized linear mixed-effects models. Method. Ecol. Evol. 2013, 4(2), 133-142. https://doi.org/10.1111/j.2041-210x.2012.00261
16. Wickham, H. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. 2016. https://doi.org/10.1007/978-3-319-24277-4
17. R Core Team. 2023 R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/. https://doi.org/10.32614/r.manuals
18. El amri, A.; Majdoub, R.; M'sadak, Y.; Aouichaoui, G. Appréciation expérimentale de l'uniformité de distribution de l'eau dans le périmètre irrigue zaafrana ii (Tunisie centrale). Larhyss J. 2012, 11, 37-45.
19. Champaneri, D.D.; Desai, K.D.; Ahlawat T.R.; Shrivastava, P.K. Assessment of various uniformity aspects under surface drip irrigation system in tomato. Int. J. Env. Clim. Change. 2023, 13(3), 47-55. https://doi.org/10.9734/IJECC/2023/v13i31680
20. Santos, F.L. Quality and maximum profit of industrial tomato as affected by distribution uniformity of drip irrigation system. Irrigation Drainage Syst. 1996, 10, 281–294. https://doi.org/10.1007/BF01102811
21. Mensah, A.C.G.; Simon, S.; Assogba Komlan, F.; Adjaïto, L.; Martin, T.; Ngouajio, M. Intensification de la culture de tomate sous filet anti-insectes en région péri urbaine du Sud-Bénin. Revue Science et Technique, Sciences Naturelles et agronomies. Sci. Technol. Health Sci. 2016, 2, 267-283. https://www.ajol.info/index.php/stss/index
22. Maboko, M.M.; Du Plooy, C.P.; Bertling, I. Comparative performance of tomato cultivars in soilless vs. in-soil production systems. Acta Hort. 2009, 843, 319-326. https://doi.org/10.17660/ActaHortic.2009.843.42
23. El-Aidy, F.A.; Hasssan, N.A.; Masoud, A.E.; El-Khateeb, E.H. Comparison between soil and soilless cultivation of autumn tomato production under spanish net-house conditions. Egypt. J. Soil Sci. 2023, 63(4), 571-579. https://doi.org/10.21608/ejss.2023.225734.1627
24. Bibi, A.; Santiago, K.S.; Yeh, J.M.; Chen, H.H. Valorization of agricultural waste as a chemiresistor H_2S-gas sensor: A composite of biodegradable-electroactive polyurethane-urea and activated-carbon composite derived from coconut-Shell waste. Polymers. 2023, 15(3), 685. https://doi.org/10.3390/polym16172504
25. Tüzel, I.H.; Meric, K.M.; Tüzel, Y. Crop coefficients in simplified hydroponic systems. Acta Horticulture. 2006, 719, 551-556. https://doi.org/10.17660/ActaHortic.2006.719.64
26. Faostat. FAO Statistic 2023. Accessed October 16, 2024. www faostat.fao.org.
27. Arouna, A.; Awi, E.; Azouma, Y.O. Amélioration de la productivité de l'eau en culture irriguée de tomate (*Lycopersicum esculentum*) en saison sèche au Sud-Togo. Bulletin de la Recherche Agronomique du Bénin (BRAB) Numéro Spécial Développement Agricole Durable (DAD) – Décembre 2018 BRAB en ligne (on line) sur les sites web ISSN sur papier (on hard copy): 1025-2355 et ISSN en ligne (on line): 2018, 1840-7099. http://www.slire.net&http://www.inrab.org
28. Ortíz, J.N.; de Juan, J.A.; Tarjuelo, J.M. Analysis of water application uniformity from a centre pivot irrigator and its effect on sugar beet (*Beta vulgaris* L.) yield. Biosyst. Eng. 2010, 105(3), 367-379. https://doi.org/10.1016/j.biosystemseng.2009.12.007
29. Hernandez, V.; Hellin, P. Increasing yield and quality of tomato cultivated under high temperature conditions through the use of elicitors. Proc. Environ. Sci. 2015, 29, 184. https://doi.org/10.1016/j.proenv.2015.07.251
30. Dorais, M. Tomato quality and flavour: The contribution of greenhouse production systems. Food Agri. Environ. 2007. 5(1), 85–102.
31. Jensen, M.H. Controlled environment agriculture in deserts, tropics and temperate regions. Acta Hort. 2002. 578, 19–25. https://doi.org/10.17660/ActaHortic.2002.578.2
32. Gruda, N. Do soilless culture systems have an influence on product quality of vegetables? J. Appl. Bot. Food Qual. 2009. 82(2), 141–147. https://doi.org/10.5073/JABFQ.2008.082.023